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ק הפטנטים תשכ"ז - 1967  
PATENT LAW, 5727 - 1967

ק ש ה ל פ ט נ ט  
Application for Patent

(שם המבקש, מענו ולגבי גוף מאוגד - מקום התאגדותו)  
I (Name and address of applicant, and in case of body corporate-place of incorpora

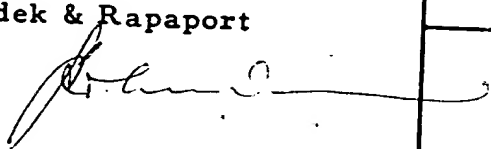
THE DOW CHEMICAL COMPANY,  
a Delaware Corporation,  
of 2030 Dow Center,  
Abbott Road,  
Midland, Michigan 48640,  
U. S. A.

העברה מאת הממציאים  
of an invention the title of which is assignment by the inventors  
1. George A. Lane 2) Arthur S. Teot 3) Harold E. Rossow  
שמה הוא  
אמצאה מכה  
Owner, by virtue  
תערוכת בעלת חילוף  
עזרה הניתן להפיכה לאחסון אנרגיה חרמית.

REVERSIBLE PHASE CHANGE COMPOSITION FOR STORING THERMAL ENERGY  
אנגלית  
(Englis

hereby apply for a patent to be granted to me in respect thereof.

בקש בזאת כי ינתן לי עליה פטנט

• בקשת חלוקה - Application of Division		• בקשת פטנט מוסף - Application for Patent Addition		• דרישה דין קדימה Priority Claim		
מבקשת פטנט from Application		לבקשה/לפטנט to Patent/Appl.		מספר/סימן Number/Mark	תאריך Date	מדינת האגוד Convention Country
No. .... dated .....		No. .... dated .....		540,726	11. 10. 1983	U. S. A.
יפוי כח: כללי / מיוחד - רצוף / בזה / עוד יגש P.O.A.: general/individual-attached/to be filed later- הוגש בענין..... המען למסירת מסמכים בישראל Address for Service in Israel Cohen Zedek & Rapaport P.O. Box 33116 Tel Aviv						
חתימת המבקש Signature of Applicant Cohen Zedek & Rapaport 				היום 1st October 1984 of the year of		
BY:				לשימוש הלשכה For Office Use		

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REVERSIBLE PHASE CHANGE COMPOSITION FOR  
STORING THERMAL ENERGY

חברות בעלת חילוץ פזה הניחן להפיכה לאחסון  
אנרגיה תרמית

ABSTRACT OF THE DISCLOSURE

A reversible liquid/solid phase change composition for storing thermal energy. The composition comprises at least one hydrated inorganic salt selected  
5 from a salt or mixture of salts that are subject to segregation of its chemical components during repeated freezing and thawing cycles, and a surface active thickening agent in the form of a cationic surfactant and selected from an amine, salts of the amine, or a  
10 quaternary ammonium salt of the amine, wherein the thickening agent is present in the hydrated salt in an amount sufficient to form a micelle structure throughout the hydrated salt to prevent such segregation.

REVERSIBLE PHASE CHANGE  
COMPOSITION FOR STORING THERMAL ENERGY

The invention generally relates to reversible liquid/solid phase change materials (PCMs) for storing thermal energy. More particularly, the invention relates to PCMs comprising a hydrated inorganic salt or  
5 mixture of salts which undergoes segregation of its chemical components during repeated freezing and thawing cycles, and a surface active thickening agent in the form of a cationic surfactant for preventing segregation of the hydrated inorganic salt components.

10 For some time, storage materials which undergo a change in phase have been employed as an attractive alternative to materials which store thermal energy as sensible heat such as, for example, by raising the temperature of water or rocks. In contrast, PCMs  
15 absorb a large quantity of latent heat during their phase change from the solid to the liquid and release it at a constant temperature as the process is reversed.

Considerable effort has been spent in identifying and testing suitable PCMs for the storage of  
20

thermal energy including the early work by Maria Telkes involving the storage of solar energy by the heat of fusion of suitable salt-hydrates and their eutectics such as, for example, sodium sulfate decahydrate

- 5 --  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$  (Glauber's salt). In ASHRAE Journal of September, 1974, pages 38-45, M. Telkes evaluated the thermal, physical and other properties of PCMs on the basis of economics, applicability, corrosion, toxicity, and availability for large scale installations.

- 10 Numerous other PCMs which store thermal energy as latent heat have been identified by G. A. Lane in Volume I of a book entitled "Solar Heat Storage: Latent Heat Materials", CRC Press, Boca Raton, Florida, 1983, pages 9-30.

- 15 Several classes of hydrated inorganic salts exist and can be generally divided into two groups:

- (1) Salt hydrates that can go through many cycles of freezing and thawing without an appreciable separation of their chemical components. Such salt  
20 hydrates can be classified as congruent melting, quasi-congruent melting, congruent isomorphous, and eutectic salt hydrates, and

- (2) Salt hydrates which undergo an appreciable segregation of their chemical components during repeated  
25 cycles of freezing and thawing. Such salt hydrates can be classified as semi-congruent melting, incongruent melting, incongruent isomorphous, hypoeutectic and hypereutectic salt hydrates.

Salt hydrates of group (1) which are "congruent melting" are hydrated salt mixtures such as, for example,  $\text{CaBr}_2 \cdot 6\text{H}_2\text{O}$ , for which, at the melting point, with solid and liquid phases in a stable equilibrium, the solid  
5 phase contains no hydrated  $\text{CaBr}_2$  other than the hexahydrate and the liquid phase contains, for every mole of  $\text{CaBr}_2$ , six moles of water plus sufficient water to form the stable hydrate of any additive materials in solution.

10 "Quasi-congruent" melting salt hydrate, such as, for example,  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$  is a semi-congruent melting salt hydrate which freezes to the metastable stoichiometric crystalline hydrate, without formation of a  
15 stable lower hydrate and melts reversibly, mimicking the behavior of a congruent melting salt hydrate.

Congruent isomorphous salt hydrate is a mixture of salt hydrate components that are fully miscible in the crystalline state in which the mixture has either 1) a minimum melting point below that of all  
20 the components and other mixtures, or 2) a maximum melting point above that of all the components and other mixtures. A congruent isomorphous salt hydrate is, for example, a mixture of 38.5 weight percent  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  and 61.5 weight percent  $\text{CaBr}_2 \cdot 6\text{H}_2\text{O}$ .

25 Eutectic salt hydrates are mixtures of two or more components mixed in such a ratio that the melting point of the mixture is lower than that of any component and the entire mixture at one and the same temperature passes from the solid form into the liquid form and  
30 vice versa. An example of a eutectic salt hydrate is one comprising 58.7 weight percent  $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  and 41.3 weight percent  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ .

In some cases, there is no satisfactory PCM in group (1) for a given application and the practitioner must choose a material from group (2). For example, greenhouses or hothouses often operate at a temperature of from 15° to 25°C, but at times there is not enough solar energy to melt a PCM, i.e. a modified  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  which has a phase transition temperature of 27°C. Thus, a PCM melting at a temperature of from 18° to 22°C is more desirable. However, there is no PCM which is completely satisfactory among those PCMs in group (1) which melt in this temperature range. Accordingly, a PCM from group (2) can be selected but must be stabilized to prevent chemical separation of its components. It is the stabilization of such PCMs which is the object of this invention.

Salt hydrates of the type herein under consideration are those hydrated inorganic salts of the class hereinbefore identified in group (2) all of which undergo transition to the anhydrous or a less hydrated form at a characteristic temperature on heating and which revert to the more hydrated form on cooling at equilibrium.

A "semi-congruent melting" PCM of group (2) has two or more hydrate forms with differing solid compositions and melting points. Such PCMs can be transformed into other hydrate forms before either complete melting or freezing occurs, resulting in a broadened melting point range. In addition, there is a temporary loss in thermal energy storage capacity. Sodium thiosulfate pentahydrate ( $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ ) is an example of a semi-congruent melting PCM.

"Incongruent melting" PCMs yield two distinct phases on melting, i.e., a saturated solution and a precipitate of an insoluble anhydrous salt. If the precipitate settles out of the solution, the anhydrous salt will not hydrate completely upon cooling and some thermal energy storage capacity will be lost with each freeze/melting cycle. Accordingly, incongruent melting, as observed with sodium sulfate decahydrate, for example, is a serious problem because it can result in a continual loss of latent heat storage capacity.

An "incongruent isomorphous" salt hydrate is a mixture of salt hydrate components that are fully miscible in the crystalline state, other than a congruent isomorphous salt hydrate. An incongruent isomorphous salt hydrate is, for example, a mixture of 46.0 weight percent  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  and 54 weight percent  $\text{CaBr}_2 \cdot 6\text{H}_2\text{O}$ .

Mixtures of components which form a eutectic other than the eutectic composition are either "hyper-eutectic" or "hypo-eutectic" hydrated salt mixtures in which the hypereutectics contain more, and the hypo-eutectics contain less of the principal component than the eutectic composition. Mixtures of  $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  and  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$  compositions other than the eutectic form the hypereutectic or hypo-eutectic salt hydrates.

In "Solar Energy Storage"; ASHRAE Journal of September, 1974, M. Telkes, reported on the performance of experiments with various thickening agents as additives, with the aim of producing a PCM in which the anhydrous salt, i.e., sodium sulfate, could not settle out by gravity. Many different thickening agents were tested including such materials as woodshavings, sawdust,

paper pulp, various types of cellulosic mixtures and methocel. Additional organic materials were tested including starches and alginates. Inorganic materials tested included silica gel, diatomaceous earth and  
5 finely divided silica products. U.S. Patent No. 3,986,969 (Telkes) discloses the use of an attapulgitic-type clay as a thickener of a PCM such as Glauber's salt ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ). M. Telkes also reported that some of these materials performed quite well for a  
10 number of cycles but that the silica gel, formed in the mixture itself, proved to be a hindrance in filling the mixture in containers because it thickened too rapidly. Moreover, some of the silica material combined with the borax nucleator and inhibited the nucleating capability  
15 of borax. None of the materials tested by M. Telkes has shown itself to be an effective agent for preventing segregation, i.e. for preventing gross movement of insoluble solids which are formed during , e.g. incongruent melting of the PCM. Thickening materials generally  
20 inhibit but do not always prevent movement of insoluble solids due to an increase in the viscosity of the composition. Accordingly, such thickening agents usually fail in time and segregation of the components of the PCM occurs.

25               Organic thickening agents which are natural polymers or derivatives thereof have been found to be unstable to hydrolysis and to bacterial and enzymatic action, all of which have the effect of shortening the lifetime of such organic thickening agents. Inorganic  
30 thickening agents, although more stable, generally are used only in containers of shallow depth, e.g., about one inch or less in depth, and are disposed in a horizontal position.

Another solution to the problem of providing a stable thickening material for PCMs is proposed by P. Kent et al. in U.S. Patent No. 4,209,413. Kent et al. propose a PCM which is stable to hydrolysis and biological breakdown in which a hydrated inorganic salt is dispersed in a hydrogel formed from a water-soluble synthetic polymer having pendant carboxylic or sulfonic acid groups cross-linked with cations of a polyvalent metal. The synthetic polymers used, which must be soluble in strong PCM salt solutions, are dispersed in the melted salt hydrate, and then reacted further in solution with cross linking agents, forming "giant molecules", which permeate the PCM mass and form a gel network. Among the gellants discovered by Kent et al are the modified acrylamide polymers.

As reported by Kent et al., an advantage of the material is that the hydrated inorganic salt is immobilized and maintained in close proximity and in small volumes throughout the hydrogel. This gelled composition minimizes any segregation of its components which could arise, after fusion of the hydrate phase, by any solid sinking to the bottom of the mixture. The synthetic polymers proposed by Kent et al. form a rubbery gel-like matrix containing the PCM and although the matrix provides for a more stable PCM, a large amount of the matrix-forming polymer is required which substantially raises the cost of the PCM. A further drawback in the use of synthetic polymers is that the heat storage capacity of the PCM is lowered and that the convective heat transfer of the PCM is inhibited. Kent et al. report that the PCM can be prepared in situ by reaction between the respective water-soluble polymer and a water-soluble salt of the polyvalent metal.

However, this requires that the container for the PCM must be filled before the matrix is fully formed or cured.

Thickening agents of the class used herein are disclosed in a U.S. Patent application by A.S. Teot et al., Serial No. 456,161, filed January 6, 1983 and published as Canadian Patent No. 1,185,779, issued on 23.4.85. A.S. Teot et al. disclose an aqueous, high density, well-bore service fluid comprising water, a water-soluble salt having a density of at least 15 lbs/gal., and a thickening agent soluble in the fluid to increase the viscosity of the fluid to a predetermined level. The thickening agent employed in the high density fluid is an amine, salts of the amine, or a quaternary ammonium salt of said amine. The water-soluble salt consists essentially of calcium chloride, calcium bromide; zinc bromide, or mixtures thereof.

The present invention resides in a thermal energy storage material comprising at least one hydrated inorganic salt having a phase change transition temperature in the range of from greater than 0°C to 140°C, wherein said hydrated inorganic salt or mixture of salts undergoes segregation of its chemical components during repeated cycles of freezing and thawing, and a surface active thickening agent in the form of a cationic surfactant and used in an amount sufficient to form a micelle structure throughout the storage material to prevent said segregation.

The term "micelle structure" herein used designates a system of electrically charged colloidal particles or ions, consisting of oriented molecules.

The surfactants used herein are viscoelastic and consist of molecules with a relatively long, lipophilic hydrocarbon chain, terminating in a hydrophilic ionic group such as amine or quaternary amine.

5 In aqueous media, the surfactant molecules form micelles by orienting themselves with the hydrocarbon "tails" together in the center of the micelle, and the ionic groups on the outside, interfacing the aqueous medium. Because of the mutual repulsion of the electrically

10 charged ionic groups, most surfactants, in aqueous solution, form spherical micelles, which are relatively ineffective at thickening the composition. However, by selecting the surface active material or by using a selected mixture of surfactants, the hydrophilic-

15 -lipophilic balance of the PCM-surfactant system of the invention has been manipulated to form cylindrical micelles. These take the form of long, rope-like structures, which permeate the solution and are extremely effective in increasing the viscosity.

20 A relatively small amount, 1-2 weight percent, of an effective surfactant is sufficient to gel the PCM and prevent segregation. Additionally, the gelled compositions appear to exhibit Bingham body or pseudo-plastic rheology. Thus, when the PCM is pumped or

25 stirred, shear thinning occurs, and the gelled composition can be transferred easily to the encapsulating containers, where it again thickens. This is a significant advantage over the hydrogel-thickened PCMs of Kent et al., which must be encapsulated before gellation is complete.

30 Many of the gelled PCM formulations also show a viscosity decrease when heated well above the PCM melting point. This also can be an aid to processing.

The term "supercooling" refers to a discrepancy between the temperature at which freezing initiates and the melting temperature of a given liquid/solid phase change material when cooled and heated under quiescent conditions.

5 Numerous PCMs have been identified with phase transition temperatures (PTT) extending over a wide range of from as low as 0°C to as high as 180°C. One such PCM is described in co-pending application Serial No. 504,763, filed June 15, 1983, <sup>now U.S. Patent No. 4,637,888</sup> (G. A. Lane et al.). The application discloses a PCM comprising an admixture of hydrated  $\text{CaBr}_2$  and  $\text{CaCl}_2$  and additionally includes a modifier selected from  $\text{KBr}$ ,  $\text{KCl}$ , or mixtures thereof. The (PTT) of this PCM, depending on the respective amounts of the salts present in the PCM varies from 7°C to 50°C. Other segregating PCM's having a (PTT) above 50°C are, for example,  $\text{MgCl}_2 \cdot 2\text{H}_2\text{O}$  which is semi-congruent melting and which has a (PTT) of 181.5°C and  $\text{SrCl}_2 \cdot 2\text{H}_2\text{O}$  which is semi-congruent melting and which has a (PTT) of 134.4°C. A segregating PCM having a (PTT) below 50°C is, for example,  $\text{Cd}(\text{NO}_3)_2 \cdot 9\text{H}_2\text{O}$  which is semi-congruent melting and which has a (PTT) of 3.5°C.

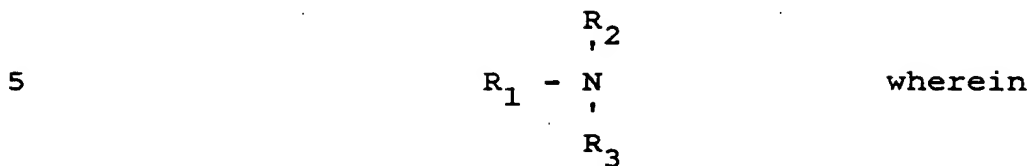
15 Numerous other inorganic PCMs and their transition temperatures are listed in Volume I of "Solar Heat Storage", by G. A. Lane; CRC Press, Inc., 1983. Many of the hydrated salts referred to in this publication are PCMs of group (2), in supra, which undergo segregation of their chemical components during repeated cycles of freezing and thawing.

30 The present invention provides a solution to the problem of segregation of chemical components in

semi-congruent melting, incongruent melting, and incongruent isomorphous salt hydrates. According to the present invention, a particular type of surface active thickening agent or surfactant is added to the inorganic PCM creating a micelle structure throughout the PCM. An advantage of the addition of this thickening agent to a PCM is that only a small amount of the thickening agent, as an additive, is needed compared to various thickening or gelling agents hereinbefore described. A further advantage is that a PCM having added thereto the micelle structure-forming thickening agent of the present invention, thins when subjected to shear or an elevated temperature, so that it can be more readily poured or pumped from one container to another container. As previously alluded to, thinning of the PCM of the present invention under shear is highly desirable since it allows mixing of a large quantity of the PCM, including the thickening agent, and subsequent pouring of the PCM from a large mixing tank into smaller containers or panels which can then be installed on location, i.e., at the building site, the hothouse, or the like.

The thickening agent employed in the present invention is a cationic surfactant which is viscoelastic and capable of forming the micellular structure in a concentrated hydrated salt solution (PCM) as hereinbefore described. The surfactant is selected from an amine (primary, secondary or tertiary), a salt of such amine, or a quaternary ammonium salt of such amine, including heterocyclic amine salts or quaternary ammonium salts wherein the nitrogen atom is present in a five- or six-member ring structure.

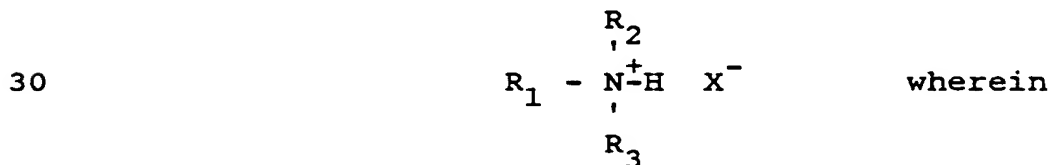
Useful amines include those corresponding to the formula:



10  $R_1$  is at least about a  $C_{16}$  aliphatic group which may be branched or straight chain and which may be saturated or unsaturated. The maximum number of carbons in the  $R_1$  group is primarily dependent on the type of  $R_2$  and  $R_3$  groups, and the concentration of the water soluble salt; preferably  $R_1$  contains no more than about 26 carbon atoms.

15  $R_2$  and  $R_3$  are independently hydrogen or a  $C_1$  to about  $C_6$  aliphatic group which can be branched or straight chained, saturated or unsaturated, and which may be substituted with a hydrophilic group which will render the  $R_2$  and/or  $R_3$  group more hydrophilic such as, 20 for example, by replacing one or more hydrogen atoms with an -OH and/or amide group.  $R_2$  and  $R_3$  groups containing a hydrophilic substituent are preferred in hydrated salts having higher electrolyte concentrations because they increase the electrolyte compatibility of 25 the surface active agent.

Salts of such amines which can be employed correspond to the formula:



$R_1$ ,  $R_2$  and  $R_3$  are the same as defined directly hereinbefore and  $X^-$  is an inorganic or organic salt forming anion.

Quaternary ammonium salts of the amines which  
5 can be employed in the present invention correspond to the formula



wherein  $R_1$ ,  $R_2$ ,  $R_3$  and  $X^-$  are the same as hereinbefore defined and  $R_4$  can independently constitute the same group as  $R_2$  or  $R_3$  except that none of  $R_1$ ,  $R_2$ ,  $R_3$  or  $R_4$   
15 are hydrogen. In addition, the  $R_2$ ,  $R_3$  and  $R_4$  groups may be formed into a heterocyclic ring structure which includes the nitrogen atom of the amine.

Preferably,  $X^-$  is an inorganic anion such as a sulfate, nitrate, perchlorate or halide. A halide,  
20 (Cl, Br or I) is preferred, Cl and Br being most preferred.  $X^-$  may also be an aromatic organic anion such as salicylate, naphthalene sulfonate, p and m chlorobenzoates, 3,5- and 3,4- and 2,4-dichlorobenzoates, t-butyl and ethyl phenates, 2,6- and 2,5-dichlorophenates,  
25 2,4,5-trichlorophenate, 2,3,5,6-tetrachlorophenate, p-methyl phenate, m-chlorophenate, 3,5,6-trichloropicolinate, 4-amino-3,5,6-trichloropicolinate, 2,4-dichlorophenoxyacetate, toluene sulfonate  $\alpha,\beta$ -naphthols, p,p'-bisphenol A. The thickening agent should be chosen  
30 such that the anion is compatible with the electrolyte present in the hydrated salt such that undesirable

precipitates are not formed. Also, the specific anion chosen will depend to some degree on the specific amine structure.

5 The thickening agent is employed in an amount which is sufficient to increase the viscosity of the PCM by at least 50 percent over the viscosity thereof without the addition of the thickening agent as measured, for example, on a Haake Rotovisco viscometer at a temperature of about 20°C and a shear rate of 160  
10  $\text{sec}^{-1}$ .

The exact quantity and the particular thickening agent or mixture of agents to be employed will vary somewhat depending on the specific PCM employed, the viscosity desired, the temperature of  
15 use, the pH of the solution, and other similar factors. The concentration of the thickening agent generally ranges from 0.05 to 5 weight percent, preferably from 0.2 to 3 weight percent, most preferably from 0.5 to 2.0 weight percent of the PCM. Simple laboratory  
20 procedures can be employed to determine the optimum conditions for any particular set of parameters. For example, when a non-protonated amine is employed as the thickening agent, the pH of the PCM can affect to some degree the effectiveness of particular amines. More  
25 acidic PCMs are required for some amines to be dissolved therein. It is thought that this is because the amine must become protonated before it will become effectively dissolved in the fluid.

Examples of thickening agents which can be  
30 employed include oleyl methyl bis(hydroxyethyl)

ammonium chloride; oleyl-bis-(2-hydroxyethyl)amine;  
erucyl-bis-(2-hydroxyethyl)-methyl ammonium chloride;  
hexadecyl-bis-(2-hydroxyethyl)-methyl ammonium chloride;  
octadecyl methyl bis(hydroxyethyl) ammonium bromide;  
5 octadecyl tris(hydroxyethyl) ammonium bromide;  
octadecyldimethylhydroxyethyl ammonium bromide; cetyl  
dimethyl hydroxyethyl ammonium bromide; cetyl methyl  
bis(hydroxyethyl)ammonium salicylate; cetyl methyl  
bis(hydroxyethyl)ammonium 3,4-dichlorobenzoate; cetyl  
10 tris(hydroxyethyl)ammonium iodide; bis(hydroxyethyl)  
soyaamine; N-methyl, N-hydroxyethyl tallow amine;  
bis(hydroxyethyl)octadecylamine; cosyl dimethylhydroxy-  
ethyl ammonium bromide; cosyl methyl bis(hydroxyethyl)  
ammonium chloride; cosyl tris(hydroxyethyl) ammonium  
15 bromide; docosyl dimethylhydroxyethyl ammonium bromide;  
docosyl methyl bis(hydroxyethyl)ammonium chloride;  
docosyl tris(hydroxyethyl)ammonium bromide; hexadecyl  
ethyl bis(hydroxyethyl)ammonium chloride; hexadecyl  
isopropyl bis(hydroxyethyl)ammonium iodide; N,N-  
20 -dihydroxypropyl hexadecylamine; N-methyl, N-hydroxy-  
ethyl hexadecylamine; N,N-dihydroxyethyl octadecylamine;  
N,N-dihydroxypropyl oleylamine; bis(2-hydroxyethyl)-  
erucylamine; N,N-dihydroxypropyl soya amine;  
N,N-dihydroxypropyl tallow amine; N-butyl hexadecyl  
25 amine; N-hydroxyethyl octadecylamine; N-hydroxyethyl  
cosylamine; cetylamine; N-octadecyl pyridinium chloride;  
N-soya-N-ethyl morpholinium ethosulfate; methyl-1-oleyl  
amido ethyl-2-oleyl imidazolinium-methyl sulfate;  
methyl-1-tallow amido ethyl-2-tallow imidazolinium-  
30 -methylsulfate.

It has been found that as the concentration  
of the hydrated salt increases the thickening agent  
should be more hydrophobic as long as solubility is

maintained. This can be achieved by employing a thickening agent having a specific combination of  $R_1$  and  $R_2-R_4$  groups to provide a proper hydrophobic lipophilic balance. It has also been found that the  $X^-$  component  
5 of the thickening agent affects, to some degree, the effectiveness of the agent in specific PCMs. For example, organic anions ( $X^-$ ) generally are found to function more effectively in lower density fluids, e.g., less than about 49 weight percent  $CaBr_2$ , because  
10 of their solubility. Thickening agents having an inorganic anion constituent are generally more effective over a broader composition range than are thickening agents containing an organic anion.

To prepare the PCMs of the present invention,  
15 the surface active thickening agent is added to the hydrated salt. Standard mixing procedures known in the art can be employed since heating of the PCM and special agitation conditions are normally not necessary. It has been found preferable, in some instances, to dissolve  
20 the thickening agent into a lower molecular weight alcohol prior to mixing it with the hydrated salt. The lower molecular weight alcohol (e.g., isopropanol) functions as an aid to solublize the thickening agent. Other well known solubilizing agents can also be employed.

25 The following Examples 1 and 2 are illustrative of a particular PCM based on  $CaCl_2$ ,  $CaBr_2$ ,  $KBr$ ,  $KCl$ , and water. Certain of these PCMs, having 6 moles of water for each gram atom of calcium, are congruent-melting and do not segregate. Others are not fully congruent-  
30 -melting and, when subjected to repetitive cycles of freezing and melting, develop a composition gradient.

The surface active thickening agent of the present invention is capable of forming a micelle structure which effectively prevents such segregation of the PCM components.

5    Test 1

A PCM of the following composition was prepared:

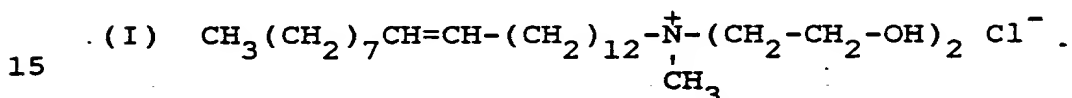
	CaBr <sub>2</sub>	48.03 weight percent
	CaCl <sub>2</sub>	11.63 weight percent
10	KBr	1.67 weight percent
	KCl	0.45 weight percent
	SrCl <sub>2</sub>	0.28 weight percent
	SrBr <sub>2</sub>	0.08 weight percent
	NaBr	0.22 weight percent
15	NaCl	0.05 weight percent
	H <sub>2</sub> O	remainder up to 100 weight percent

This sample composition was tested by alternately freezing at 0°C and melting at 45°C in an  
20    air bath, while recording the temperature of the sample. Desirably, stable PCMs, e.g., PCMs which are congruent melting, drop in temperature during freezing until the phase transition temperature is reached, remain at that temperature until the material is frozen, and then  
25    again drop in temperature. During melting, the process is reversed. A sample of the PCM of the above composition showed this desirable behavior for about six freeze-melt cycles, freezing and melting at 19°C. However, thereafter the temperature plateau at 19°C became shorter and more  
30    sloping, vanishing after 26 cycles. This phenomenon was accompanied by a segregation of the sample composition. This test illustrates that this PCM, without a cationic surfactant which is capable of forming a micelle structure

throughout the PCM, will initially show a good freeze-melting behavior but will begin to segregate after a few freeze-thaw cycles.

Example 1

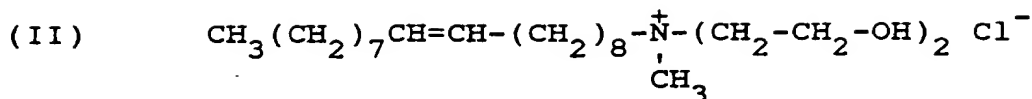
5           A sample of the same hydrated salt composition as used in Test 1 was prepared. To 100 grams of this sample was added 1.3 grams of a mixture of 10 weight percent isopropanol as a thinner in 90 weight percent quaternary surfactant and was blended into the  
10           hydrated salt composition. The surfactant, an ethoxylated quaternary alkylene amine had the following structure.



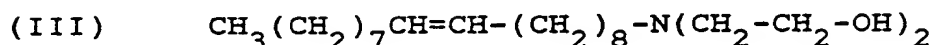
          The PCM took on a thickened and gelled consistency, indicating an extensive formation of micelle structures in the PCM. When subjected to over  
20           200 freeze-thaw cycles at a temperature of 0°C and 45°C, this PCM maintained its freezing plateau at 19°C and did not segregate. This example of the invention shows that the addition of the micelle-forming surface active thickening agent stabilizes the PCM and prevents  
25           segregation of its components.

Example 2

          A sample of the same hydrated salt composition used in Test 1 was prepared and blended with a surfactant of a mixture of an amine and a quaternary  
30           amine. To 100 grams of the salt composition was added 1.5 grams of an ethoxylated quaternary alkylene amine of the following formula:



5 and 0.5 grams of the corresponding amine of the following formula:



This example of the invention also showed that the addition of the surfactant to the hydrated  
10 salt composition caused a thickening of the PCM which when subjected to the same freeze-thaw cycles as in Example 1, showed stability for more than 20 cycles, i.e., without segregation of the salt components.

#### Test 2

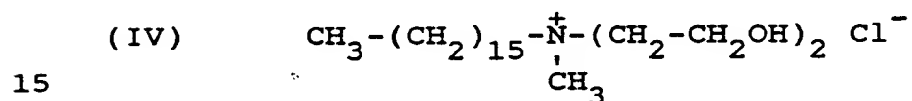
15 A further sample of the following hydrated salt composition was prepared:

	$\text{CaCl}_2$	33.3 weight percent
	$\text{MgCl}_2$	9.4 weight percent
20	$\text{H}_2\text{O}$	remainder, up to 100 weight percent

This salt composition was tested by repetitive freezing at a temperature of 6°C and melting at 35°C in a water bath. After four cycles, the composition began to segregate, with increased separation of the salt  
25 components on subsequent cycles. The composition is a semi-congruent melting material which is prone to segregation, as demonstrated in this test.

Example 3

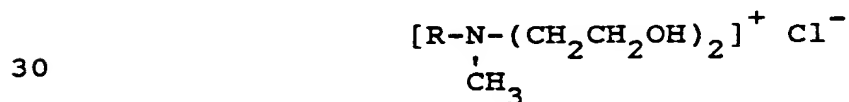
A sample of the same hydrated salt composition of Test 2 was prepared and blended with a surfactant of a mixture of amine and a quaternary amine. To a 100  
5 gram sample of the hydrated salt composition was added 1.5 grams of a mixture of 10 weight percent isopropanol and 90 weight percent of the ethoxylated quaternary alkylene amine as defined in Formula (I), and 0.5 grams of a surfactant mixture of 25 weight percent isopropanol  
10 and 75 weight percent of a surfactant of the following formula:



The resulting PCM was blended and took on a thickened or gelled consistency, again indicating an extensive formation of micelle structures in the PCM. The PCM was then subjected to the same freeze-thaw  
20 cycling procedure described hereinabove and was found to be stable for over 60 cycles, with no segregation of the PCM having been observed. This example of the invention again shows that the addition of the micelle-forming additive stabilizes the PCM against segregation.

25 Example 4

To 100 g of sodium sulfate decahydrate (Glauber's salt) at 25°C was added 1.3 g of a surfactant of the structure:



wherein R was the erucyl group,  $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_{12}-$ ,  
and 1.0 g of gellant in which R was cetyl,  $\text{CH}_3(\text{CH}_2)_{15}-$ .  
The mixture was stirred vigorously for 40 minutes while  
the temperature was raised gradually to  $40^\circ\text{C}$ . A thick,  
5 uniform gelled composition resulted.

Glauber's salt is infamous for its tendencies  
to segregate when alternately frozen and thawed. The  
surfactant of the invention holds the promise of main-  
taining the anhydrous  $\text{Na}_2\text{SO}_4$  and saturated  $\text{Na}_2\text{SO}_4$   
10 solution, which form when the material is heated above  
the transition point, in close proximity, so that  
rehydration can occur when the temperature is reduced  
below the transition point.

Example 5

15 150 g of the following PCM composition was  
prepared:

53.9 weight percent  $\text{CaBr}_2 \cdot 6\text{H}_2\text{O}$   
42.9 weight percent  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$   
1.9 weight percent KBr  
20 1.4 weight percent KCl

Starting at  $25^\circ\text{C}$ , 2.0 g of the erucyl-based surfactant  
and 1.5 g of the cetyl-based surfactant of Example 4  
were added. The temperature was raised to  $40^\circ\text{C}$ , and  
the mixture was stirred vigorously for two hours. A  
25 good, thick, uniform gelled PCM resulted.

Although this isomorphous mixture is congruent  
melting, compositions varying only slightly on either  
side of the minimum-melting mixture tend to segregate  
during freezing. Thus, it is also desirable to stabilize

this PCM by thickening, since some variation in composition is bound to occur during the manufacture of a commercial heat storage composition.

Example 6

5           To 150 g of  $\text{MgBr}_2 \cdot 10\text{H}_2\text{O}$  at  $50^\circ\text{C}$  was added  
1.5 g of the cetyl-based surfactant. After the mixture  
was stirred vigorously for two hours, 2.0 g of the  
erucyl-based surfactant of Example 4 was added. After  
80 minutes further stirring, a good, thick PCM  
10 composition resulted.

          This hydrate is semicongruent melting, forming  
a lower hydrate and saturated  $\text{MgBr}_2$  solution during  
freezing. Thickening of this PCM with the surfactant  
of the invention inhibits gravity separation of these  
15 two phases, so that rehydration can occur during  
melting, to form a uniform mixture once again.

Example 7

The following composition was prepared:

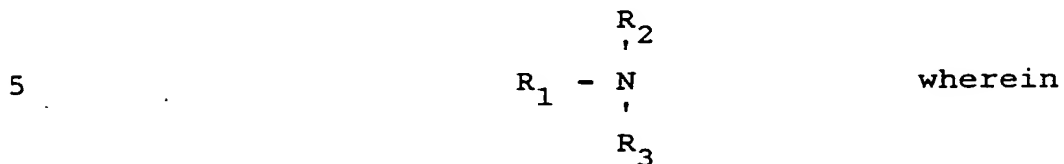
          43.6 weight percent  $\text{CaCl}_2$   
20           0.95 weight percent  $\text{SrCl}_2$   
          1.6 weight percent  $\text{KCl}$   
          0.4 weight percent  $\text{NaCl}$   
          53.4 weight percent  $\text{H}_2\text{O}$

          1.6 g of the erucyl-based surfactant was blended with  
25 1.5 g of the cetyl-based surfactant of Example 4 until  
a uniform mixture was obtained. This was then added to  
the salt solution above, the temperature was raised to  
 $60^\circ\text{C}$ , the composition was stirred vigorously for  
40 minutes, and 0.24 g  $\text{BaO}$  nucleator was blended in. A  
30 good, thick gel was obtained.

CaCl<sub>2</sub>·6H<sub>2</sub>O is semicongruent melting, and segregates mildly in freeze-thaw cycling. It can be made congruent melting by addition of potassium ion, along with strontium and/or sodium ion. The melting  
5 point can be lowered from about 27-28°C to about 20°C by adding enough extra water to give 7.44 moles per mole of CaCl<sub>2</sub>. This composition is no longer congruent melting, and will segregate unless it is stabilized by the procedure described hereinabove.

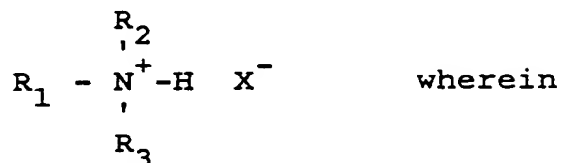
1. A thermal energy storage material comprising at least one hydrated inorganic salt having a phase change transition temperature in the range of from greater than 0°C to 140°C, wherein said hydrated  
 5 inorganic salt or mixture of salts undergoes segregation of its chemical components during repeated cycles of freezing and thawing, and a surface active thickening agent in the form of a cationic surfactant and used in  
 10 an amount sufficient to form a micelle structure throughout the storage material to prevent said segregation.

2. The storage material of Claim 1, wherein said surfactant is selected from the group consisting of: (a) an amine corresponding to the formula

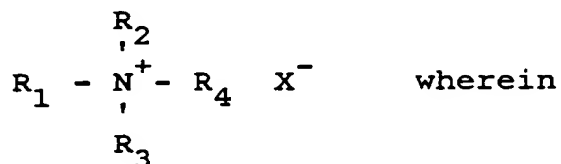


$R_1$  is at least about a  $C_{16}$  aliphatic group which may be branched or straight chained and which may be saturated or unsaturated;

10  $R_2$  and  $R_3$  are each independently, hydrogen or a  $C_1$   
to about  $C_6$  aliphatic group which can be branched or  
straight chained, saturated or unsaturated and which  
may be substituted with a group which renders the  $R_2$   
and/or  $R_3$  group more hydrophilic; (b) salts of said  
15 amine corresponding to the formula



20  $R_1$ ,  $R_2$  and  $R_3$  are the same as defined hereinbefore  
and  $X^-$  is an inorganic or organic salt forming anion;  
or (c) a quaternary ammonium salt of said amine cor-  
responding to the formula

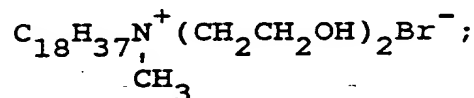
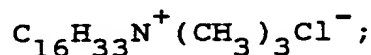


25  $R_1$ ,  $R_2$ ,  $R_3$  and  $X^-$  are the same as hereinbefore  
defined and  $R_4$  independently constitutes a group which  
has previously been set forth for  $R_2$  and  $R_3$ , none of  
 $R_1$ ,  $R_2$ ,  $R_3$  or  $R_4$  are hydrogen, and the  $R_2$ ,  $R_3$  and  $R_4$   
30 groups of the amine salt and quaternary ammonium salt  
may be formed into a heterocyclic five- or six- member  
ring structure which includes the nitrogen atom of the  
amine.

3. The storage material of Claim 1 wherein  
said surfactant is employed in an amount of from 0.05  
to 5 percent by weight of the storage material.

4. The storage material of Claim 1, wherein said hydrated inorganic salt is selected from salts which are semi-congruent melting, incongruent melting, incongruent isomorphous salt hydrates or mixtures which are hypereutectic or hypoeutectic mixtures.

5. The storage material of Claim 1, wherein the surfactant comprises at least one member selected from the group consisting of oleyl methyl bis(2-hydroxyethyl)ammonium chloride; erucyl-bis-(2-hydroxyethyl)-methyl ammonium chloride;



10 bis(2-hydroxyethyl)oleylamine; bis(2-hydroxyethyl)-erucylamine; bis(2-hydroxyethyl)soyaamine; bis(2-hydroxyethyl)tallowamine; bis(2-hydroxyethyl)octadecylamine;  $C_{22}H_{45}(CH_3)_2N^+CH_2CH_2OHBr^-$  and  $C_{20}H_{41}(CH_3)_2N^+CH_2CH_2OHBr^-$ .

6. The storage material of Claim 2, wherein  $X^-$  is  $Cl^-$  or  $Br^-$ .

7. The thermal energy storage material of Claim 1, wherein said surfactant is added in an amount sufficient to increase the viscosity of the storage material by at least 50 percent.

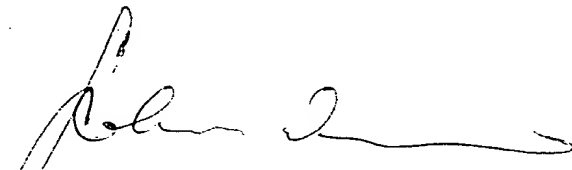
8. An energy storage device comprising an encapsulating means having a reversible liquid/solid

phase change composition hermetically sealed in said encapsulating means to prevent the evaporation of water from the composition, said composition comprising at least one hydrated inorganic salt having a phase transition temperature of from greater than 0°C to 140°C, said salt being selected from salts or mixture of salts which undergo segregation of their chemical components during repeated cycles of freezing and thawing, and a surface active thickening agent in the form of a cationic surfactant and used <sup>in</sup> an amount sufficient to form a micelle structure throughout the storage material to prevent said segregation.

9. A method of storing energy comprising the steps of preparing a reversible liquid/solid phase change composition having a phase change transition temperature in the range of from greater than 0°C to 140°C, selecting said composition from at least one hydrated inorganic salt or mixture of salts which undergoes segregation of its chemical components during repeated cycles of freezing and thawing, and adding a surface active thickening agent in the form of a cationic surfactant to the hydrated salt or mixture of salts in an amount sufficient to form a micelle structure throughout the hydrated salt to prevent segregation of the inorganic salt components, introducing the phase change composition into an encapsulating means for use as an energy storage device, and hermetically sealing the encapsulating means to prevent the escape of water vapor from the encapsulating means.

10. The method of Claim 9, wherein the surfactant is added to the hydrated salt prior to encapsulation in the encapsulating means.

11. The method of Claim 9, wherein the surfactant is added to the hydrated salt within the encapsulating means and prior to hermetic sealing of the encapsulating means.



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